

The Social and Cultural Awareness Disparity in Open Natural Ecosystems Research – A Systematic Review

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Abstract

Globally, two-thirds (59%) of the earth's terrestrial habitats comprise non-tree-covered forests and open natural ecosystems (ONEs). Studies indicate that ONEs are often overlooked in conservation science, policy, and practice due to biome awareness disparity (BAD). In this context, a review study was conducted to explore the existence of other potential areas of awareness disparity within research studies related to ONEs. Adopting a systematic bibliometric analysis, twenty-six articles published in peer-reviewed journals were reviewed to gain new insights. Our review notices that research studies on ONEs are heavily skewed towards the biodiversity and biophysical aspects of ONEs, and socio-cultural studies are found to be minimal. In addition to BAD, the review indicates that ONE's research may also show signs of social awareness disparity (SAD) and cultural awareness disparity (CAD). However, a much larger study covering research on the different types of ONEs, including hot and cold deserts, tundra, flooded/saline plains, rock outcrops, boulder and rubble fields, wetlands, peatlands, heathlands, grasslands, savannah ecosystems, and mangroves, has to be studied to ascertain our observations about SAD and CAD. Our review opens the doors for further research and discussion, as the existing literature may not provide sufficient information on the social and cultural heritage factors related to ONEs around the world.

Keywords

Open ecosystems; Open natural ecosystems; Biome awareness disparity; Social awareness disparity; Cultural awareness disparity; Grasslands

Introduction

The United Nations Decade of Ecosystem Restoration (UN-DER), which spans from 2021 to 2030, advocates for the protection and restoration of ecosystems worldwide for the benefit of both people

and nature (IUCN, 2022). Similarly, the United Nations General Assembly has designated the year 2026 as the International Year of Rangelands and Pastoralists (IYRP). The objective of IYRP, 2026, is to promote an understanding of rangelands and people who use them around the world (FAO, 2022). A clear understanding of global ecosystems is crucial for achieving the objectives of international initiatives such as UN-DEER and UN-IYRP, 2026. The new map of terrestrial World Ecosystems derived by Sayre *et al.* (2020) identifies a total of 431 World Ecosystems, of which 278 are natural or semi-natural ecosystems, including forestlands, shrublands, grasslands, bare areas, and ice/snow regions. The Sayre *et al.* (2020) new World Ecosystems map, however, does not include oceanic/aquatic ecosystems. When oceanic/aquatic ecosystems are included, the number of world ecosystems could be much greater than 431. Unquestionably, all the world's ecosystems are quintessential for the existence of human society. It is quite natural to assume that all the different ecosystems across the globe enjoy the same level of awareness and appreciation from people. The reality, however, could be a bit different from the notion of equal importance and appreciation of all the ecosystems around the world. The study of Silveria *et al.* (2021) indicates that few ecosystems are more appreciated than others. For instance, the tree-covered forest ecosystems enjoy greater attention and appreciation than the treeless open natural ecosystems (here onwards, ONEs), in conservation science, policy, and practice.

Silveria *et al.* (2021) observe that ONEs around the world, especially in the tropics, suffer from biome awareness disparity (here onwards, BAD) (Silveria *et al.*, 2021), and are subjected to negligence both in conservation policies and practice (Bond, 2019; Bond, 2021; Madhusudan and Vanak, 2022). The study suggests that BAD is pervasive in restoration of ONEs, and restoration studies are highly skewed and focused on tree-covered forest biomes. Silveria *et al.* (2021) indicate that nearly 90% of the global studies on ecosystem restoration are focused on tree-covered forest areas. While the representation of ONEs such as the tropical desert and xeric shrublands, flooded grasslands and savannas, montane grasslands and shrublands, tropical and subtropical grasslands, shrublands and savannas is either minimal or altogether absent from the global ecosystem restoration studies. BAD suggests the existence of clear negligence and a wide research gap with regard to ONEs. Silveria *et al.* (2021) study prompts to question of whether the disparity of ONEs is limited to just BAD, or there are other potential functions of ONEs that also suffer from disparity and negligence in research, policy, and practice?

Nearly two-thirds (59%) of the earth's terrestrial habitats comprise non-tree-covered forests and open natural ecosystems (ONEs) (Dinerstein *et al.*, 2017; Madhusudan and Vanak, 2022; Li *et al.*, 2024). It was estimated that 58.5 percent of the total terrestrial ecosystems are covered under non-forest ecosystems, comprising the hot and cold deserts, tundra, and soils that are too shallow, or that are often flooded or saline and hostile to support tree growth (Bond, 2019; Dinerstein *et al.*, 2017). ONEs also include rock outcrops, boulder and rubble fields (Fitzsimons and Michael, 2017), wetlands, peatlands, as well as heathlands, grasslands, and savannah ecosystems (Bond, 2019). ONEs exhibit high levels of endemism and are often home to highly endangered flora and fauna (Bond, 2019; Bonkougou, 2001; Madhusudan and Vanak, 2022; Vanak *et al.*, 2024). Tropical savannas have one of the highest densities of wild mammalian species (both carnivores and herbivores) in the world (Sankaran and Ratnam, 2013).

Across the globe, vast areas that are warm enough and wet enough to support tree growth are often dominated by grasslands, shrublands, savannas, and open woodlands (Bond, 2019; Bond, 2021; Wulf, 2015). The lack of tree covers on seemingly warm and wet landscapes, especially in the tropics, remains a puzzle to many scientists (Bond, 2019). In the following paragraphs, we discuss the extent of ONEs in India and Canada to gain a better understanding of ONEs at regional scales.

Canada has one of the largest terrestrial and aquatic ecosystems in the world, which includes the largest forest, tundra, prairie, wetland, freshwater, and oceanic ecosystems. Approximately 25 percent of Canada's landmass is comprised of tundra, while 4 percent features prairie grasslands, 2 percent is covered by permanent snow, and 28 percent encompasses various natural and semi-natural ecosystems, including woodlands, shrublands, alpine tundra, barren land, wetlands, and water bodies. Canada's boreal zone comprises the subarctic forest, woodland, heathland, grassland, wetland, and water, covering an area of 5.5 million km², from Newfoundland and Labrador to the Yukon (Statistics Canada, 2022). In the country, prairies, tundra, and other natural and semi-natural ecosystems comprise 59 percent of the land area, while forested regions occupy only 36 percent. However, ONEs are in general termed as '*barrens*' in Canada, a legacy of the early European explorations of Canada (Francis, 1987; Peplinski, 2009).

Approximately 10 percent (319.675 km²) of India's geographical area can be classified as semi-arid ONEs (Jain 2022; Madhusudan and Vanak, 2022; Sudhira 2022). The ONEs in India comprise open grasslands, savannas, hot and cold deserts, ravines, rocky boulders, outcrops, and escarpments, wetlands, freshwater and saltwater marshes, mudflats, and mangroves (Madhusudan and Vanak, 2022; Srivathsa *et al.*, 2023). Besides, ONEs are the lifeline of an estimated 15-18 million pastoralist families and fodder security of millions of livestock populations in India (Madhusudan and Vanak, 2022; McGahey *et al.*, 2014). However, such unique ecosystems, often with highly endemic and endangered wildlife and immense socio-economic value to the local communities, are classified as '*wastelands*', as per India's land-use and conservation policy (PIB, 2019; Riedel *et al.*, 2021; Madhusudan and Vanak, 2022; Srivathsa *et al.*, 2023).

The classification of ONEs as wastelands in India is attributed to colonization and colonial misunderstanding of the unique biodiversity, ecosystems, and human societies of the tropics (Jain, 2022; Paul and Vanak, 2020). The continuation of the colonial misclassification of ONEs as wastelands has facilitated indiscriminate diversion of ONEs to non-ecological uses, resulting in fragmentation and degradation. For instance, between the period 1880 and 2010, India lost over 20 million hectares of forest land for agriculture, plantations (often with alien tree species), renewable energy (wind and solar energy plants), other infrastructure development projects, and defence purposes (Paul and Vanak, 2020). Many large-scale solar energy projects have been established on ONEs, "deemed wastelands", leading to serious conflicts in India. Since 2017, at least fifteen conflicts related to solar and wind energy projects have been reported across India (Shivaprakash, 2022).

With the advancements in scientific research and technology, the knowledge and understanding of ONEs has improved tremendously in the past decade. There was a significant understanding of ONEs, particularly in the disciplines of biodiversity,

ecology, palaeontology, soil sciences, fire regimes, animal and plant interactions, and satellite imagery and remote sensing (Andermann *et al.*, 2022; Cardoso, Beckett and Bond, 2023; Estes *et al.*, 2025; Gopalakrishna *et al.*, 2024). However, BAD is a reminder that the existing public and policy awareness and action with regards to global ONEs is far from significant, especially in the context of climate change, rapid loss of biodiversity and species extinction, impact on local income and livelihoods, threats to biocultural diversity and cultural heritage, and customary rights of the Indigenous Peoples and local communities across the globe.

BAD (Silveira *et al.*, 2021) establishes the existence of awareness disparity between ecosystems (tree-covered vs non-tree-covered). Building on this background, our review study examines the existence of other potential awareness disparities in research studies related to ONEs. It was evident that open-treeless ecosystems (hot and cold deserts, tundra, flooded or saline plains, rock outcrops, boulder and rubble fields, wetlands, peatlands, heathlands, grasslands, and savannah ecosystems) can be technically called as ONEs. However, our research is limited to two broad criteria: (1) recent studies, published in the past five years (during 2021-25); and (2) studies that explicitly use “ONEs” in the title of the study. These limitations were introduced due to time constraints and the explorative nature of the review study. Therefore, the findings of our review should be considered preliminary and explorative, with the potential to conduct more extensive future studies and open doors for debate and discussion.

Methodology

This section adopts a systematic bibliometric analysis (Donthu *et al.* 2021; Passas, 2024) of literature published on ONEs. The two broad criteria selected for the literature review are recently published articles (time) and relevance of the study (theme/title) to the objectives of the present study. Articles published in peer-reviewed journals during the past five years (2021-25) were selected for review, following Amobonye *et al.* (2024). The selection of resources follows a systematic search, following the methods of Rewhorn (2018) and Xiao and Watson (2019). Google Scholar search engine was used for searching relevant published works. A systematic search was conducted using the keywords “open ecosystems” and “open natural ecosystems” (ONEs). The term “open natural ecosystems” (ONEs) was chosen over “open ecosystems” for systematic searches as it is more specific and less commonly used in information technology and computer science, thereby minimizing irrelevant results in the context of this study.

About 75 articles were downloaded from the internet for further analysis. Based on the two broad criteria, time (published during 2021-25) and theme (presence of the word open ecosystems/open natural ecosystems in the title), the sample was narrowed down to 26 peer-reviewed articles. The selected articles were further reviewed, coded, and analysed: (i) bibliometric information (i.e. year of publication, first author/ co-authors); (ii) information on the open natural ecosystems (i.e. use of this term in the title, abstract, keywords, text); (iii) main argument with regards to ONEs; (iv) information of the characteristics defining ONEs; and (v) potentially missing information from the documents (i.e. social, cultural, economic), (Mattalia *et al.*, 2024). The observations mainly include the publication pattern, the broad thematic areas and main arguments of

the papers, the terminology used for referring to ONEs, and the status of socio-economic focus in articles selected for review.

Results

It was observed that research on ONEs shows a positive trend (Figure 1). There was an 800% increase in the number of publications on ONEs from the year 2021 to 2024. However, the year 2023 and 2024 shows a plateau in terms of the number of articles published on ONEs (Figure 1). Maybe it is too early to predict the trend in the year 2025, but it is safe to say that publications on ONEs (as of the end of February 2025), are already 300% more than studies published during 2021. Of the total 26 articles selected for review, 3.7% were published in 2021; 14.81% were published in 2022; 33.33% were published in each year 2023 and 2024; and 11.11% were published in 2025 (as of February 2025).

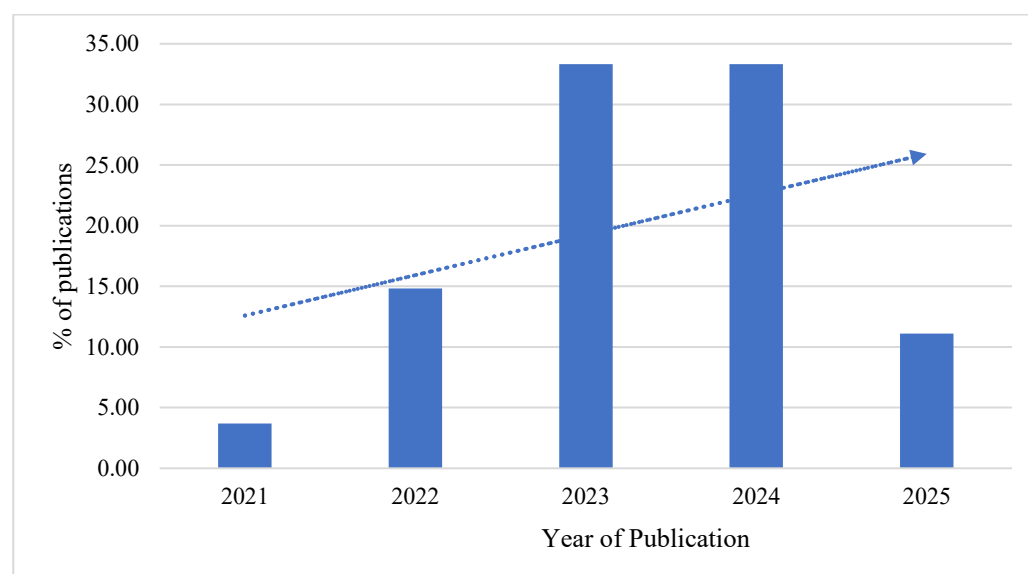


Figure 1: The trend in research publications on Open Natural Ecosystems during 2021-25 (n=26)

The broad themes of research observed among the studies selected for review (n=27), are biodiversity/ biodiversity conservation (31%); ecosystem/ ecosystem management (23%); biophysical (19%), technology (digital) (7%), paleo-ecology (8%); and studies focusing on biodiversity and biophysical aspects, biodiversity and ecosystem management and socio-economic aspects accounts to 4% each (Fig. 2). It was found that biodiversity and ecosystem related studies are the most popular research areas, followed by biophysical aspects of ONEs among the selected studies. It was observed that studies representing socio-economic status are almost insignificant, and no studies were observed on socio-cultural aspects of ONEs among the reviewed studies (Table 1).

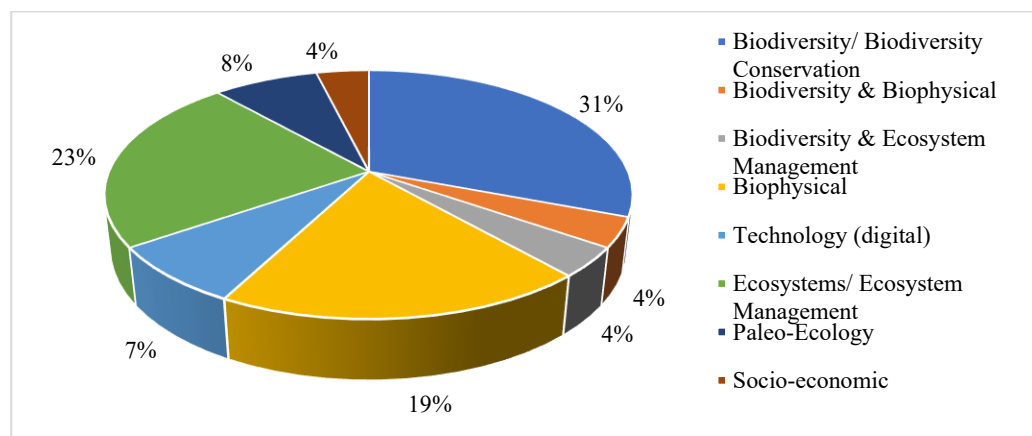


Figure 2: The broad themes of research on ONEs published during 2021-25 (n=26)

The broad thematic areas (Figure 1) were extracted from analysing the main arguments of the selected articles. The details of the authors, year of publication, detailed analysis of the main arguments of the research, focus of research, and geographical focus of each study are presented in table 1.

Table 1: The main arguments of the research studies published on ONEs during 2021-25 (n=26)

S. No.	Authors	Year	Title	Main argument	Research focus	Geography focus
BIODIVERSITY AND BIODIVERSITY CONSERVATION						
1.	Bharadwaj <i>et al.</i>	2024	Assessment of long-term trends in a threatened grassland bird community using daily bird lists	Studies the population trends of grassland bird species in a central Indian grassland–agriculture mosaic landscape, which has been experiencing several land-use changes.	Biodiversity	South Asia
2.	Heimbuch <i>et al.</i>	2023	Grasshopper abundance and offtake increase after prescribed fire in semi-arid grassland	The study examines the relationship between fire and increases in the content of grass crude protein, which in turn increased the density of and offtake by grasshoppers relative to unburned mixed-grass prairie ecosystems.	Biodiversity	North America
3.	Leo <i>et al.</i>	2023	Spontaneous renaturalization of open ecosystems in the hills of Brescia seen through the bird community	The study finds that populations of seven open area bird species have declined as a result of a sharp decline in their natural habitat, such as traditional crops, flat open areas, soils with low grass, and often with rocky outcrops etc. The decline in agro-pastoral practices, absence of fires, increase in percentage of tree cover, and decline in quarries	Biodiversity	Europe

S. No.	Authors	Year	Title	Main argument	Research focus	Geography focus
				were found to be the drivers of decline in open area bird species in the study area.		
4.	Mikula <i>et al.</i>	2023	Bird tolerance to humans in open tropical ecosystems	The study examines animal tolerance to humans and argues that traits predicting the direction and magnitude of human coexistence among tropical animals are poorly studied. The study suggests that bird species inhabiting open tropical ecosystems show less tolerance towards humans. There was a difference in the levels of human tolerance among the bird species that are found in the rural and urban areas. Also, larger bird species, with larger clutches and enhanced flight ability, are less tolerant of humans. Tolerance levels also varied according to seasons.	Biodiversity	Africa, South America, and Australia
5.	Pilon <i>et al.</i>	2023	Challenges and directions for open ecosystems biodiversity restoration: An overview of the techniques applied for Cerrado	The study assesses the effectiveness of both active and passive restoration techniques applied for the restoration of open ecosystems (Cerrado tropical savanna), and their impact on target plant species. The study suggests that active restoration performs better with regard to restoration of the target species population.	Biodiversity	South America
6.	Srivathsa <i>et al.</i>	2023	Prioritizing India's landscapes for biodiversity, ecosystem services, and human well-being	The study highlights the mismatch in priority sites when unsuitable criteria are used to derive a conservation value of an ecosystem. It points out that open natural ecosystems, such as open grasslands with unique endemic flora and fauna, are inappropriately classified as wastelands as per India's land-use and conservation policy.	Biodiversity Conservation	South Asia
7.	Tolgyesi <i>et al.</i>	2024	Restoration of open ecosystems in the face of climate change	The special issue dedicated to addressing the growing challenges associated with restoration of open ecosystems includes studies focusing on the knowledge gaps, challenges in identifying the right target	Biodiversity and ecosystem management	Global

S. No.	Authors	Year	Title	Main argument	Research focus	Geography focus
				sites, genetic composition, and plant species for restoration, and an appropriate methodological toolkit for selection of appropriate target plant communities. Furthermore, the review identifies the role of soil microbes in grassland recovery.		
8.	Tsakalos <i>et al.</i>	2022	Plant clonality in a soil-impooverished open ecosystem: insights from southwest Australian shrublands	The study argues that clonality is key to resilience, and it is advantageous under different environmental conditions and disturbances like fires. Results of the study suggest that clonality is more widespread in Australian shrublands than previously thought, and distinct plant communities are distinguished by specific suites (or lack) of clonal growth organs.	Biodiversity	Australia
9.	Vaudo <i>et al.</i>	2024	Low-density migratory beekeeping induces intermediate disturbance effects on native bee communities in Tibetan Plateau alpine meadows.	The study argues that beekeeping involving the keeping of large numbers of honey bees could create ecological disturbance. Results of the study suggest that the presence of apiaries has a negative impact on the native bee populations, likely through displacement. It was observed that in locations where apiaries were present earlier but are currently absent have witnessed a resurgence of native bee populations has been witnessed.	Biodiversity	East Asia
10.	Wang <i>et al.</i>	2023	Tree cover and its heterogeneity in natural ecosystems are linked to large herbivore biomass globally.	The study finds that tree cover in strictly protected areas is inversely related to large herbivores, especially browsers; however, the spatial heterogeneity is positively associated with the same. On the contrary, fire is inversely related to both tree cover and spatial heterogeneity.	Biodiversity and biophysical	Global
BIOPHYSICAL						
11.	Cardoso <i>et al.</i>	2023	How forests survive alongside flammable open	The study argues that fire-sensitive forest patches exist within a matrix of flammable	Biophysical	Africa

S. No.	Authors	Year	Title	Main argument	Research focus	Geography focus
			ecosystems: conservation implications for Africa	ecosystems as alternate stable states and explores how forests existed for many millennia alongside the flammable open ecosystems.		
12.	Estes <i>et al.</i>	2025	Riverscours Ecosystems of Eastern Unglaciated North America: A Review	The study defines riverscours ecosystems and argues that these ecosystems are often overlooked and poorly understood grassland systems. Such systems are found within river and stream floodplains in mountainous or hilly regions. These ecosystems are shaped and maintained by high-energy floods and scouring by winter ice, in combination with edaphic factors.	Biophysical	North America
13.	Gopalakrishna <i>et al.</i>	2024	The distribution and drivers of tree cover in savannas and forests across India	The study argues that Indian savannas have been historically misclassified as degraded forests and are targeted for tree-planting. The study demonstrates the relationship between water availability and topography (tree-grass dynamics) using a remotely sensed tree cover metric. The study, however, could not ascertain a relationship between fire and shortfall due to limited data on fires.	Biophysical	South Asia
14.	Silveira <i>et al.</i>	2022	Where to Graze? An Edaphic Grassland Perspective of Grazing Management in Grassy Ecosystems	The study argues that not all grasslands are equal and need different grazing and management systems. To substantiate, the shows edaphic grasslands, which have poor drainage, extremely low moisture holding capacity, and exceptionally poor soils as an example. It suggests that the vegetation of edaphic grasslands is predominantly affected by soil conditions as well as climate, and disturbances. Therefore, the management practices should be different from disturbance-maintained grasslands.	Biophysical	South America

S. No.	Authors	Year	Title	Main argument	Research focus	Geography focus
15.	Stevens <i>et al.</i>	2022	Grassy ecosystems in the Anthropocene	The study argues that grassy ecosystems are poorly defined and protected due to legacies of colonial narratives that described them as wastelands, deforested or derived, which makes it easy to clear and convert them into agricultural lands. It examines the cumulative effect of climate change, land conversion, and erosion on the ecosystem services of grassy ecosystems.	Biophysical	Global
<i>DIGITAL TECHNOLOGIES</i>						
16.	Tripathi <i>et al.</i>	2024	Optimizing Riparian Habitat Conservation: A Spatial Approach Using Aerial and Space Technologies	The study evaluates the condition of riparian habitats using a nested approach to remote sensing, combining satellite data and UAV imagery with an overall accuracy of 98%, thus suggesting the efficiency of such tools for reach-level assessment of freshwater habitats, especially of small stream networks.	Digital technology	South Asia
17.	Madhusudhan and Vanak	2022	Mapping the distribution and extent of India's semi-arid open natural ecosystems	The study argues that non-forested open natural ecosystems are highly threatened due to land conversion, which could have implications for biodiversity and the livelihoods of pastoralists in India. The study produces accurate digital maps of ONEs across the country. The study assumes that the open data source will be useful to policymakers and planners to exclude these habitats when considering climate change-related projects like plantations, renewable energy, and other development projects.	Physical (digital map)	South Asia
<i>ECOSYSTEMS AND ECOSYSTEM MANAGEMENT</i>						
18.	Beebe <i>et al.</i>	2024	Fire versus herbivory for oak woodland restoration: burning achieves short-term	The replicated experimental study evaluates the impact of targeted browsing and prescribed burning for achieving diversity and abundant native ground flora in	Ecosystem Management	North America

S. No.	Authors	Year	Title	Main argument	Research focus	Geography focus
			structural and compositional objectives, whereas browsing alone fails to reduce stem densities and promote ground flora.	a two-layered oak woodland. Results suggest that short-term fire is necessary to reduce midstory densities, increase light availability, and promote native ground flora abundance, which may not be achieved with targeted browsing alone.		
19.	Dias <i>et al.</i>	2025	Open ecosystems restoration: a global review shows biases and mismatches between theory and practice	The review study examines studies published on restoration of open ecosystems from 2011 to 2021 and found that restoration of open ecosystems is concentrated in North America and Europe, with 75% of restored areas originating in these continents. The restored areas are often small, have multiple indicators for assessment, and the assessments were of short duration, without any established control or reference areas for comparison. Common restoration activities include tree and shrub management, soil management, seeding, and the transfer of plant material.	Ecosystem Management	Europe and North America
20.	Overbeck and Pillar	2024	Forest-biased terminology does not help to include open ecosystems in conservation policies.	The study argues that inadequate terminology, especially the use of the term 'Forest Code' for the main conservation law and the term 'deforestation' for loss of all types of ecosystems in conservation policies and debates in Brazil, is not only confusing but also jeopardizing conservation goals, such as the conservation of natural grasslands. It points out that the term deforestation is not applicable to a grassland, as a grassland cannot be 'deforested', because it does not have trees. This mismatch and lack of appropriate language and terminology put open ecosystems at risk.	Ecosystem Management	South America

S. No.	Authors	Year	Title	Main argument	Research focus	Geography focus
21.	Manzano <i>et al.</i>	2023	Underrated past herbivore densities could lead to misoriented sustainability policies	The study estimates the carrying capacity of the Earth's grazed ecosystems by comparing the current levels of herbivory with the Late Pleistocene period and the pre-industrial era. The study suggests that the levels of herbivory during the Late Pleistocene and pre-industrial era are likely to be consistently higher than the current levels. The study calls for designing appropriate policies for biodiversity conservation, ecosystem restoration, food production, and climate change based on baselines to avoid overestimation of current herbivory levels.	Ecosystem Management	Global
22.	Rodrigues <i>et al.</i>	2024	Origin of sandy substrates controlling the distribution of open vegetation ecosystems in Amazonia	The study investigates the formation of white-sand ecosystems in the lowlands and highlands of Amazonia and draws inferences for biodiversification or extinction events leading to current biogeography patterns in Amazonia.	Ecosystem	South America
23.	Tavşanoğlu and Bernardi	2024	Old-growth grasslands of Central Anatolia (Türkiye) require better conservation and management.	The study points out that grasslands (including steppes and forest steppes) are often misclassified as degraded ecosystems and maintains that recent studies suggest that grasslands are ancient and biodiversity-rich ecosystems that persisted through anthropogenic disturbances and climate change. The study emphasizes the need to re-evaluate current land management practices, particularly afforestation projects, which may undermine the resilience of grassland ecosystems to climate change.	Ecosystem Management	Middle East
PALEO-ECOLOGY						
24.	Andermann <i>et al.</i>	2022	The origin and evolution of open habitats in North	Reconstructs the emergence of open habitats in North America using Bayesian deep learning	Paleo-ecological	North America

S. No.	Authors	Year	Title	Main argument	Research focus	Geography focus
			America inferred by Bayesian deep learning models.	models, utilizing fossil evidence, geological models, and paleoclimatic proxies		
25.	Feurdean <i>et al.</i>	2025	Moisture availability versus grazing and burning as drivers of the Holocene Forest-grassland coexistence in Europe: A case study from open ecosystems of south-eastern Romania	The study finds that fluctuations in forest-grassland cover closely mirror moisture availability and changes in the growing season in the Black Sea region. While diverse broadleaved forest dominated during increased moisture availability, more drought-tolerant herbaceous cover flourished during drier intervals. The study suggests that disturbances by fire and herbivores fluctuated over time. These fluctuations were further influenced by human activities like deforestation, altering the composition and extent of steppe and forest-steppe vegetation.	Paleo-ecological	Europe
<i>SOCIO-ECONOMIC</i>						
26.	Ahoyo <i>et al.</i>	2023	Sociodemographic , environmental, and biological factors affecting uses of plants from open ecosystems: Insights for improved livelihoods and biodiversity conservation	Focuses on plants used in traditional medicine and highlights the conservation status of woodlands and savannas in Benin, Africa	Socio-economic	Africa

A comprehensive summary of the major research themes and prominent areas of study is illustrated in figure 2 and detailed in table 1. It was observed that studies covering biodiversity, ecosystem, biophysical, paleo-ecological, and technology-related studies dominate the research on ONEs (Table 2). Geographically, the research studies are evenly spread across the globe, covering major continents of Asia, Europe, the Americas, Australia, and the global (Table 2). However, studies related to socio-cultural aspects of ONEs are not adequately represented among the studies selected for the review.

Table 2: The dominant themes, the geographical, and social focus among studies published on ONEs during 2021-25 (n=26)

<i>S. No.</i>	<i>Year of Publication</i>	<i>Dominant Theme</i>	<i>Geographic Focus</i>	<i>% of studies on Socio-economics (n=26)</i>
1.	2025	Ecosystem Management, Biophysical, Paleo-ecology	Europe & North America	33%, (n=3)
2.	2024	Biodiversity and Ecosystem Management	South Asia, East Asia, South America, Middle East, Global	NA, (n=9)
3.	2023	Biodiversity and Ecosystem Management	Africa, Europe, Australia, South America, Global	44%, (n=9)
4.	2022	Biophysical and Technology	North America, South Asia, Australia, Global	20%, (n=5)
5.	2021	Biophysical and Biodiversity	Global and South America	NA, (n=2)

Language and terminology are extremely important for the representation of ONEs. Overbeck and Pillar (2024) argue that inadequate terminology, especially the use of inappropriate terms like 'deforestation' for loss of all types of ecosystems, in the main conservation law-policies and debates, not only leaves people confused but also jeopardizes the conservation goals, such as the conservation of natural grasslands in Brazil. In this context, eleven major types of ecosystems were represented in the review. The most popular ecosystem types that were referred to in combination with “open” in the studies are open-ecosystems (92.59%), open-grasslands (33.33%), open-vegetation (25.93%), open-habitat (18.52%), open-landscape (18.52%), open-savanna (18.52%), open-tree-canopy (18.52%), open-woodlands (14.81%), open-scrub/shrub (11.11%), and others (33.33%). A range of terms were used to represent ONEs in the reviewed studies. The list of terms used for the representation of ONEs in studies is presented in table 3.

Table 3: The representation of ONEs in the research studies published during 2021-25 (n=26)

<i>Major types</i>	<i>The different terms used for the representation of ONEs in studies selected for the review</i>	<i>% of Articles</i>
Ecosystem	open ecosystem, open natural ecosystem, open flammable ecosystems, open ecosystem-rangelands, semi-arid open natural ecosystems, open tropical ecosystems,	92.59
Grassland	open-habitat grasslands, open grass-dominated habitats, open grassy landscapes, open tree-grass landscapes, open grasslands, open grassy ecosystems, open riverside grasslands, open grasslands with shrubs and scattered trees,	33.33
Vegetation	open vegetation, openness and heterogeneity of vegetation, open shrub-dominated vegetation, open vegetation ecosystems, open vegetation substrates, open vegetation patches,	25.93
Habitat	open-habitat grasslands, open grass-dominated habitats, open and heterogeneous habitats,	18.52

<i>Major types</i>	<i>The different terms used for the representation of ONEs in studies selected for the review</i>	<i>% of Articles</i>
Landscape	open landscapes, open parts of the landscapes, open grassy landscapes, open tree-grass landscapes, open florally diverse landscapes,	18.52
Savanna	open savannas, open savanna ecosystems, open canopy savannas,	18.52
Tree	open tree crowns, open tree canopy, open grasslands with shrubs and scattered trees, open stands, open canopy,	18.52
Woodlands	open woodlands, open Oak woodland, open woodland-outcrop,	14.81
Shrub/ Scrub	open shrub-dominated vegetation, open grasslands with shrubs and scattered trees, open shrubby vegetation, open shrublands, open scrub, open shrubland,	11.11
Others	open biome, open mid-stories, open stand, open lands, open and sun-exposed, open sites, open areas, open zone, open tropical areas, open riparian areas, open flood-prone zones, open sand barrens, open pasture, open meadows, open environments, low-stature forests, open herbaceous areas,	33.33

The research on ONEs is predominantly focused on biodiversity and biophysical aspects of ONEs. The review also yielded studies on social aspects related to ONEs. The social research of ONEs was found to be insignificant and was not as pronounced as biodiversity and biophysical research studies. Although the review found 6 (22.22%) articles with content related to socio-economic aspects related to ONEs, only one article (4%) out of the 27 studies reviewed was primarily focused on sociodemographic factors related to ONEs (Table 4). There were no studies found on socio-cultural or biocultural diversity-related topics in the studies selected for the review. The two major social groups referred to in the studies were traditional healers and pastoralists. The other aspects of human society represented in the literature were cultural landscapes, cultural indicators, cultural burning, oral traditions, ethnobotanical knowledge, human health, domestic livestock, and co-existence (Table 4).

Table 4: The representation of social/ human society aspects in studies published on ONEs during 2021-25 (n=26)

<i>S. No.</i>	<i>Authors</i>	<i>Year</i>	<i>Title</i>	<i>Social focus (n=6)</i>
1.	Ahoyo <i>et al.</i>	2023	Sociodemographic, environmental, and biological factors affecting uses of plants from open ecosystems: Insights for improved livelihoods and biodiversity conservation	Traditional healers, ethnobotanical knowledge, traditional medicine, oral traditions, primary health care
2.	Feurdean <i>et al.</i>	2025	Moisture availability versus grazing and burning as drivers of Holocene forest-grassland coexistence in Europe: A case study from open ecosystems of south eastern Romania	Human activity, cultural landscapes, cultural indicators, cultural burning, pastoralism,
3.	Leo <i>et al.</i>	2023	Spontaneous renaturalization of open ecosystems in the hills of Brescia seen through the bird community	Agro-pastoralism, cultural burning, agriculture, quarries

S. No.	Authors	Year	Title	Social focus (n=6)
4.	Madhusudan and Vanak	2022	Mapping the distribution and extent of India's semi-arid open natural ecosystems	Nomadic pastoralism, livelihoods, livestock,
5.	Manzano <i>et al.</i>	2023	Underrated past herbivore densities could lead to misoriented sustainability policies.	Pastoralism, livestock, coexistence,
6.	Srivathsa <i>et al.</i>	2023	Prioritizing India's landscapes for biodiversity, ecosystem services, and human well-being	Human health, socio-ecological systems

Discussion

The observations of our review suggest that research on ONEs is heavily skewed towards biodiversity and biophysical aspects (96% of the studies) of ONEs, and research on socio-cultural aspects (4% of the studies) of ONEs is not significant. Srivathsa *et al.* (2023) subscribe to the notion that ecological processes are the result of a complex interplay between ecological and *social* systems and suggest that sustainability cannot be achieved without fostering the links between *human* and natural systems (Bennett, 2015; Haines-Young, 2010; Ostrom, 2009). The study points out that global pandemics like COVID-19 have not only prompted us to recognize the links between human health, biodiversity, and ecosystem integrity but also reminded us of the challenges in achieving the ambitious goals and targets set under the Post-2020 Global Biodiversity Framework, especially when the global socio-economic systems are disrupted in COVID-19-like scenarios. The study emphasizes the importance of prioritizing socio-ecological research in both academic discourse and policy-making.

Is society brought to the forefront in research and discussion on ONEs? Do the existing studies identify clearly who is the social and who are in the social in the context of ONEs? Without knowing what the social fabric of ONEs is and who is in the social, how will we know who will be impacted and who will be benefited from ONEs? We will discuss these questions in the following discussion, referring to our observations in studies selected for the review.

An estimated 3.5 billion people, especially in developing countries, depend on medicinal plants as a part of their primary healthcare, and most of the medicinal plant resources are primarily collected from wild plant populations (Bodeker *et al.*, 1997). Ahoyo *et al.* (2023) maintain that plants can be viewed as cultural and economic markers of human history (Balick and Cox, 1996; Kamari *et al.*, 2009). For centuries, ethnobotanical knowledge has been accumulated by traditional healers and it is passed down the generations through oral traditions. Such traditional ethnobotanical knowledge mostly remains specific to specific social groups (Ahoyo *et al.*, 2023; Tamboura, Kabore and Yameogo, 1998). Both the sociocultural factors (Ahoyo *et al.*, 2018; Beltran-Rodriguez *et al.*, 2014; Houehanou *et al.*, 2011) and ecological factors (Akerreta *et al.*, 2007; Albuquerque, 2006; Voeks, 2004) are known to influence ethnobotanical knowledge and traditional medicinal practices (Dapar *et al.*, 2020).

Ahoyo *et al.*'s (2023) study on ethnobotanical knowledge related to woodlands and savannas in Benin suggests that sociodemographic factors such as ethnicity, source of knowledge, membership position, age, instruction level, and activity significantly influence the ethnomedicinal knowledge. The Assede *et al.* (2023) study maintains that socio-ecological factors combined with ecological factors act as key regulators of vegetation growth, therefore crucial for the management of woodlands and savannas in Benin. Therefore, it is vital to integrate such factors into a comprehensive plan for knowledge conservation, which could have a positive impact on biodiversity conservation and ecosystem management.

Feurdean *et al.* (2025) mention that palaeoecological studies indicate that humans may have used fire regimes to exploit fertile soils in open ecosystems, which are relatively easier to clear and cultivate than tree-covered forests (Turner, Roberts and Jones, 2008; Vannière *et al.*, 2011; Feurdean *et al.*, 2013; Leys *et al.*, 2018). The study also suggests that human activity contributed to the reduction of tree cover and the transformation of open ecosystems into cultural landscapes some ~ 3800 years ago. Similarly, Leo *et al.* (2023) suggest that the sun-exposed open areas of the Brescia hills were man-made since the beginning of the 11th century. Both local sheep flocks and huge transhumant pastoralist contingents were foraging the Brescia hill areas, thereby contributing to the maintenance of pseudo-steppes in these areas (Leo *et al.*, 2023; Menant, 1993). However, the steppe areas have significantly shrunk after the Second World War, following the abandonment of agro-pastoralism in this region. Leo *et al.* (2023) observe that the land-use of the Brescia hills area witnessed a steady increase in vineyards after the 13th Century, reaching the lowest forest cover and maximum extent of agriculture and pastoralism around the 1950s (Belfanti and Taccolini, 2008). Since the 1950s, the Brescia hills region has experienced a significant decline in agro-pastoral practices, leading to the swift and natural proliferation of shrubs and woodlands (Benayas, Bullock and Newton, 2008). The cessation of human activities led to the reclamation of open areas by tree-covered forests, except for rock outcrops and primitive grasslands (Leo *et al.*, 2023). Results of the study suggest that the decline in agro-pastoral practices and quarries, absence of fires, and increase in percentage of tree cover were found to be positively related to the decline in open area bird species in the Brescia hills area.

Madhusudan and Vanak (2022) uphold that open ecosystems support the livelihoods of several million nomadic pastoralists and their indigenous livestock across the globe (Sharma *et al.*, 2003; Davies and Hatfield, 2007; FES, 2012; Bond, 2019; Bond, 2021). For instance, more than 50 per cent of the fodder for India's 500 million livestock directly comes from ONEs (grasslands, scrub, and open thorny forests) (Singh *et al.*, 2006). The majority of the conventional climate change and biodiversity conservation studies frown upon pastoralism and domestic livestock as the major drivers of global problems like an increase in methane emissions causing global warming, overgrazing causing desertification, spreading zoonotic diseases to wildlife, displacement of wildlife through competition for scarce fodder resources, and exacerbating soil erosion through trampling, among others. In contrast to traditional studies, Manzano *et al.* (2023) adopt a pragmatic approach that advocates for the conservation of open ecosystems through support for domestic livestock and pastoralism. The study argues that earlier studies on the estimation of methane concentrations (Smith *et al.*, 2016) and herbivore densities

(Barnosky, 2008), before the Quaternary mass extinction and the pre-industrial era, have certain limitations and uncertainties with regard to their accuracy.

The study argues that current herbivore densities per km² across the globe are within the same range as the Mammoth Steppe (Zimov *et al.*, 2012) densities at the beginning of the Holocene of ca. 10 tonnes/km² (Bakker *et al.*, 2016). However, the study points out that herbivore density is way below natural levels in protected areas outside Africa, which is particularly concerning because of the vital role mammal herbivory plays in shaping the ecosystems (Fløjgaard *et al.*, 2022). Manzano *et al.* (2023) found from Fløjgaard *et al.* (2022), study that higher densities of herbivores were observed in specific protected areas that are surrounded by large open landscapes of East Africa. These large areas surrounding the protected areas may allow large-scale wild herbivore migrations, and such areas could be attributed to the prevalence of pastoralist economies in that region (Griffith *et al.* 2020; Manzano *et al.*, 2023). The presence of higher herbivore densities could be explained through large-scale landscape matrices preserved through complex traditional land-use practices of pastoralism in the area (Manzano *et al.*, 2023). Furthermore, the study also maintains the possible coexistence between pastoralism and wild herbivores in the region (Schieltz and Rubenstein, 2016). Manzano *et al.* (2023), suggests that it is important to understand and acknowledge the role of domestic livestock and extensive pastoral systems could plan in maintaining ecological functions of ecosystems (nutrient recycling, tree growth and regeneration, seed dispersal, weed control, fire suppression, pollinator facilitation, among others), around the world, especially in the context of dwindling large wild herbivore populations.

Sustainable management of rangelands is often deeply ingrained in the socio-cultural fabric of pastoralist communities around the world. For instance, the Nanda-Gaoli, a semi-nomadic pastoralist people native to the Indian state of Maharashtra, observe “*Bhaldev festival*”, one of the major traditional festivals of the Nanda-Gaoli people, celebrated annually during the monsoon season. It involves worshipping the *lavhan* grass (*Cyperus rotundus*), as the Nanda-Gaoli people believe that Lord Krishna (a Hindu God) resides inside it. Scientifically, the way the festival is celebrated contributes to the sustainable management of the *lavhan* grass and the grasslands, which are fundamental for the fodder security of the livestock and economic security of the Nanda-Gaoli people (Kalokar and Siripurapu, 2020). Similarly, the *dob puja* (the festival of wetlands), another traditional festival of Nanda-Gaoli people, contributes to the conservation and sustainable management of wetlands (Shahane *et al.* 2024). Bird *et al.* (2008) found that cultural burning fire regimes practiced by Aboriginal peoples in Australia, for hunting small game like monitor lizards, feral cats, and blue-tongued skinks, contribute to species and habitat diversity and richness, among the fire-adapted landscapes. The study found that Aboriginal women specialized in managing small-scale cultural burnings to hunt small game, which is also correlated to species and habitat diversity and richness.

Overbeck and Pillar (2024) point out that the use of inappropriate terms and vocabulary in the main conservation law policies and debates leaves people confused and jeopardizes the conservation goals of natural grasslands in Brazil. They further argue that the term deforestation does not apply to a grassland, as a grassland cannot be 'deforested', because it does not have trees. This mismatch and lack of appropriate language and terminology put open ecosystems at risk. Given the issues surrounding

conventional scientific and policy terminology, it is essential to consider the following question: Are we sufficiently acquainted with the Indigenous terminology and concepts related to ONEs? Are the Indigenous terms and terminologies and traditional knowledge considered and included in conservation and restoration activities of ONEs?

Siripurapu *et al.* (2024) found that cattle pastoralists in the Deccan Plateau region can identify more than fifteen different native grass species that cattle graze upon in the tropical savannas of the region. However, the local terminology hardly finds a place in the mainstream grasslands conservation policies and programs of India. Faisal Moola's field observations in the Miawpukek First Nation Reserve suggest that the Mi'kmaq First Nations people traditionally refer to heathlands as *mish*. The Mi'kmaq First Nations people often identify bogs as the black bog (bad bog) and the yellow bog (good bog) (Speller and Forbes, 2022). Heathlands and bogs usually have some stories or folklore associated with them. The Mi'kmaq First Nations people often associate bogs with wicked spirits. But such traditional terms and cultural narratives seldom find their way into the conventional conservation policies related to ONEs. Lourenco, Fitchett and Woodborne, (2023) study on peatland definitions suggests that physical and chemical properties of peatlands have been studied extensively, while studies on the socio-cultural definitions of peatlands remain either absent or insignificant. In Canada, Inuits have a very vivid and detailed reproduction of traditional place names across mediums, including their language, songs, folklore, paintings, and oral histories (Peplinski, 2009). Despite the rich traditional knowledge of the Inuit and their culturally significant place names, these elements are largely absent from Canada's official maps. The lack of documentation and reproduction of the traditional place names on the official Canadian maps has many negative consequences for the Indigenous Peoples' sense of pride, ownership, and land stewardship, traditional knowledge, and cultural reproduction (Peplinski, 2009). Furthermore, it was observed from the review that ONEs are more or less very well defined biophysically in research, but they are poorly understood socially and inadequately described or constructed culturally in the reviewed studies. Biophysically, ONEs are defined as either barrens, wastelands, grasslands, or savannas, but how can ONEs be defined socially or culturally? What are the social and cultural characteristics of ONEs? How can research studies engage with defining and describing the social and cultural characteristics of ONEs? And understand the traditional socio-cultural construction and reproduction of ONEs in conventional research?

Conclusion

Our review notices that research studies on ONEs are heavily skewed towards the biodiversity and biophysical aspects of ONEs, and socio-cultural studies are found to be minimal. Out of the 26 reviewed studies, only one study was primarily focused on sociodemographic aspects of ONEs. Five other studies were also found to cover social aspects of ONEs, but the social component is used to provide a background to the primary focus of those studies, which were predominantly focused on biophysical, biodiversity, or ecosystem management of ONEs. The review could identify only two social groups associated with ONEs – traditional healers and pastoralists. Information about the other social groups that may be closely associated with ONEs remains scanty and insufficient in the reviewed studies. While it is true that ONE's research, especially in the tropics, suffers from BAD, our review indicates that ONE's research may also

show signs of social awareness¹ disparity (SAD) (Barinua, Okilo and Waripamo, 2022; Liu and Chng, 2024) and cultural awareness² disparity (CAD) (Constantin, Vida, and Popescu, 2015; Kaihlanen, Hietapakka and Heponiemi, 2019). However, a much larger study covering research on the different types of ONEs, including hot and cold deserts, tundra, flooded/saline plains, rock outcrops, boulder and rubble fields, wetlands, peatlands, heathlands, grasslands, savannah ecosystems, and mangroves, has to be studied to ascertain our observations about SAD and CAD.

Our review opens the doors for further research and discussion, as the existing literature may not provide sufficient information on the social and cultural heritage factors related to ONEs around the world. Such knowledge and information gaps may lead to difficulty in knowing which social groups will benefit and which social groups will be affected by the conservation and restoration of ONEs, especially in the context of the UN-DER 2021-2030 and other climate change-related global programmes and projects. The current research may not provide enough information on what aspects of local Indigenous and socio-cultural heritage related to ONEs are at stake and how to take mitigative measures to prevent loss of local Indigenous and socio-cultural heritage diversity around the world. Perhaps the less we debate about social and cultural aspects of ONEs, the closer we move them towards the colonial construct of *Terra Nullius* (barrens and wastelands), and further away from the concept of the Territories of Life.

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¹ Social awareness can be defined as an in-depth knowledge and understanding of the social norms, codes, cultures, values, beliefs, perspectives, social setups, and environment of other individuals, groups, or communities, and applying such understanding when interacting with them.

² Cultural awareness can be defined as the ability to recognize, comprehend, and appreciate the diversity, differences, and similarities among different cultures, encouraging and fostering respectful interactions and effective communication between people from different cultures in diverse settings.

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Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

<i>Contribution</i>	<i>Author 1</i>	<i>Author 2</i>	<i>Author 3</i>
Conceived and designed the research or analysis	No	Yes	No
Collected the data	No	Yes	Yes
Contributed to data analysis & interpretation	Yes	Yes	No
Wrote the article/paper	Yes	Yes	Yes
Critical revision of the article/paper	Yes	No	No
Editing of the article/paper	Yes	No	No
Supervision	Yes	No	Yes
Project Administration	No	Yes	Yes
Funding Acquisition	No	No	No
Overall Contribution Proportion (%)	40	30	30

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PRISMA Checklist

Section/topic	#	Checklist item	Reported on page #
TITLE (& AUTHOR)			
The Social and Cultural Awareness Disparity in Open Natural Ecosystems Research – A Systematic Review			
Kanna K. Siripurapu ¹ , Helina Jolly ² , and Faisal Moola ³			
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Title	1	Identify the report as a systematic review, meta-analysis, or both.	1 & 2
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	2-4
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	1, & 4
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	NA
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	4
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	6-18
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	4
Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	4
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	4
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	4



PRISMA Checklist

Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	NA
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	NA
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	NA

Page 1 of 2

Section/topic	#	Checklist item	Reported on page #
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	NA
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	NA
RESULTS			
Study selection	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	5
Study characteristics	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	5-20
Risk of bias within studies	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	NA
Results of individual studies	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	NA
Synthesis of results	21	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	NA
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	NA
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	NA
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	20-23
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	4
Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	23-24
FUNDING			



PRISMA Checklist

Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	24
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